GREEN DEGUMMING PROCESS OF RAMIE FIBER
Thermal Effect and Optimization

by

Guoliang LIU[a*], Dan TIAN[b], Bangze ZHOU[a], Yumeng ZHANG[a], Tao XU[a], Hongzhi ZHAO[c], and Chunxia WANG[a]

[a] College of Textile and Clothing, Yancheng Institute of Technology, Yancheng, China
[b] National Engineering Laboratory for Modern Silk, College of Textile and Clothing Engineering, Soochow University, Suzhou, China
[c] College of Information Engineering, Yancheng Institute of Technology, Yancheng, China

Original scientific paper
https://doi.org/10.2298/TSCI1904447L

Ramie is a kind of natural fibers, it requires degumming process before it can be used as a raw material for various applications. The traditional treatment uses alkali, which is not an environmentally friendly process. In this paper, ramie fibers are degummed using sodium percarbonate, which causes no any negative environmental problems, and its decomposition, hydrogen peroxide, is a clear liquid, it can be used as an oxidizer, bleaching agent and antiseptics for surface treatment of ramie fibers. Effect of temperature and concentration of sodium percarbonate on the degumming process are studied theoretically and verified experimentally. Finally an optimal degumming process is suggested for maximal weight ratio of degummed ramie fiber to raw bast.

Key words: *ramie, mathematical model for degumming process, sodium percarbonate, temperature, non-covalent interaction, decomposition, bilevel optimization*

Introduction

Silk is the most famous natural fiber in the world [1], it is obtained from a cocoon through a degumming process [2], other natural silks have been exploited, for example, the snail-based nanofibers [3]. Ramie is another natural fiber, it is a flowering plant widely harvested in China, and is one of the oldest fiber crops, having a history of at least six thousand years [4-8]. Ramie has the longest and strongest natural fiber in textile industry, however, before ramie fiber could be used in textile, it requires chemical processing to degum the fiber. The traditional chemical degumming method is a complex process, which is neither an economic nor an eco-friendly way, and an economic and environment-friendly degumming method with simple process and low cost is very much needed [5]. This paper suggests a chemical-free degumming process using sodium percarbonate.

Experimental design and theoretical development

The ramie bast samples were supplied by Hualong Hemp Industry Co. Ltd., Anhui province, China. All chemicals used in our experiment were analytical pure and used without further treatment and purification.

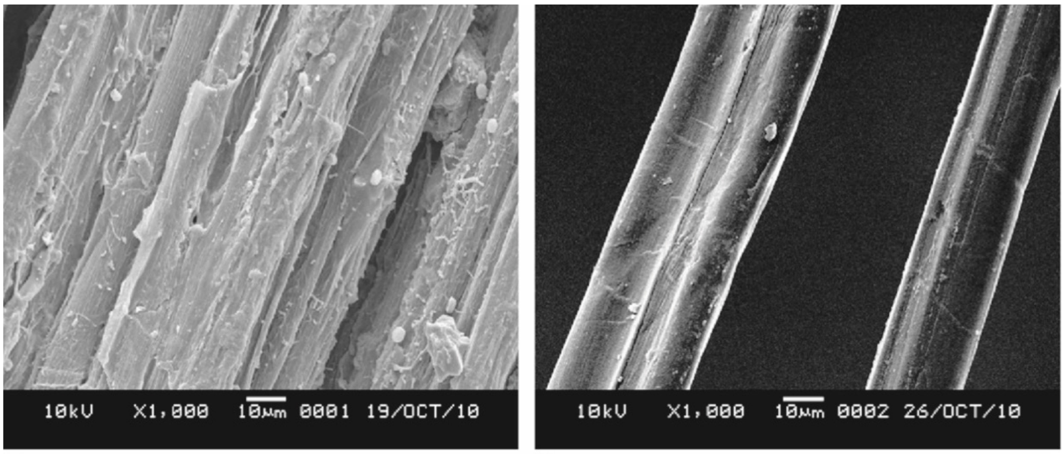
* Corresponding author, e-mail: liuguolian1114@163.com

A degumming solution using deionized water as solvent was prepared with 20% sodium percarbonate, 2% sodium silicate, 2% sodium polyphosphate, 2% chelating agent, and 2% alkali resistant penetrant.

Degumming process was carried out by soaking 15 kg ramie bast into the degumming solution, where the solution temperature rose at a rate of 2 °C per minute to a required temperature for 2.5 hours. The degumming temperature was set as 50 °C, 60 °C, 70 °C, 80 °C, 90 °C, and 100 °C, respectively.

Surface morphology of ramie fiber

The SEM images of raw bast and degummed ramie fiber were illustrated in fig. 1, revealing a clear and effective degumming capability of our technology. The raw one has obviously an unsmooth surface, fig. 1(a), while a very smooth ramie fiber was observed after the simple degumming process, fig. 1(b). The gummy materials in surface of raw bast were completely removed. The surface morphology of the degummed ramie fibers was more smooth than those by the traditional chemical treatment, so it is a promising and green technology for industrial applications.



(a) (b)

Figure 1. The SEM illustrations; (a) raw ramie bast; (b) degummed ramie fiber

Degumming temperature

Degumming temperature is an important factor in the degumming process, the effect of degumming temperature on weight ratio of degummed ramie fiber to raw bast is illustrated in fig. 2.

As degumming temperature increases, degumming capability increases, the gummy materials in surface of raw bast were gradually removed from the surface of the raw ramie bast. The weight ratio of the degummed ramie fiber to the raw bast can be described by the following eq. (1):

$$\frac{\mathrm{d}R}{\mathrm{d}T} = k(R_\infty - R) \tag{1}$$

with initial condition:

$$R(0) = R_0 \tag{2}$$

where R is the ratio of the degummed ramie fiber, T [°C] – the temperature, k – the degumming coefficient, R_0 and R_∞ – the the initial ratio at $T = 0$ °C and at a temperature infinite large, respectively.

The solution of eq. (1) reads:

$$R = R_\infty - (R_\infty - R_0)\mathrm{e}^{-kT} \tag{3}$$

The constants involved in eq. (3) can be determined experimentally. Using the experimental data given in fig. 2, we have:

$$R = 81 - (81 - 98)\mathrm{e}^{-0.015T} = 81 + 17\mathrm{e}^{-0.015T} \tag{4}$$

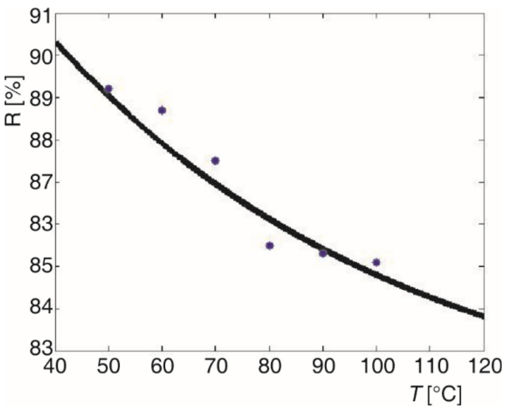


Figure 2. The effect of degumming temperature on weight ratio of degummed ramie fiber to raw bast; *points: experimental data; continuous line: theoretical prediction; the concentration of sodium percarbonate was 20%, degumming time is 2.5 hours*

When the temperature tends to infinite large, we have $R \approx 81\%$. Sodium percarbonate ($2Na_2CO_3 \cdot 3H_2O_2$) is an eco-friendly product, its aqueous solution's pH and concentration can be easily controlled. In this paper, the concentration was 20%. As an oxidizing agent, the decomposition of sodium percarbonate reads:

$$2Na_2CO_3 \cdot 3H_2O_2 = 2Na_2CO_3 + 3\ H_2O_2 \tag{5}$$

$$2H_2O_2 = 2H_2O + O_2\uparrow \tag{6}$$

The hydrogen peroxide is a clear liquid, it can be used as an oxidizer, bleaching agent and antiseptic in our experiment.

The decomposition process of sodium percarbonate in degumming solution with raw bast is different from that in aqueous solution.

The decomposition with respect to temperature in aqueous solution can be written in the form:

$$\frac{\mathrm{d}C}{\mathrm{d}T} = -K(T)C \tag{7}$$

where C is the concentration of sodium percarbonate, K – a temperature-dependent coefficient, which can be written in a power of temperature:

$$K(T) = k_0 T^n \tag{8}$$

where k_0 and n are constants.

The solution of eq. (7) reads:

$$C = C_0 \exp\left(-\frac{k_0}{n+1}T^{n+1}\right) \tag{9}$$

Decomposition of sodium percarbonate in degumming process is different from that in aqueous solution. Non-covalent interactions between the gummy materials in surface of raw bast and sodium percarbonate will greatly affect the decomposing process. The effective temperature can be approximately written as $T_\infty - T$, where T_∞ is the temperature when the sodium percarbonate decomposed completely. The decomposition process of sodium percarbonate in degumming solution with raw materials can be similarly obtained which reads:

$$C = C_0 \exp\left[-\frac{k_0}{n+1}(T_\infty - T)^{n+1}\right] \quad (10)$$

The constants involved in eq. (10) can be determined experimentally, and eq. (10) becomes:

$$C = 0.85\mathrm{e}^{0.033(95\text{-}T)} \quad (11)$$

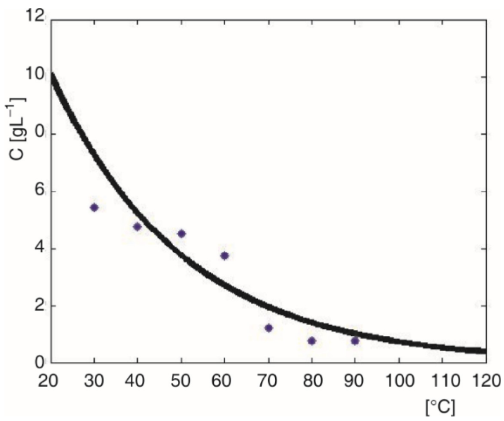


Figure 3. Decomposition process of sodium percarbonate in degumming solution with raw materials; *dots: experiment data; continuous line: theoretical prediction*

Decomposition process of sodium percarbonate in degumming solution with raw materials is illustrated in fig. 3.

Optimization degumming

The optimal degumming process is to maximize R at a suitable temperature and a suitable decomposing of sodium percarbonate. It can be described by the following bilevel optimization:

$$R = 81 + 17\mathrm{e}^{-0.015T} \to \max \quad (12)$$

Subject to:

$$C = 0.85\mathrm{e}^{0.033(95\text{-}T)} \to \max \quad (13)$$

The optimization is easy to be solved without any difficulty. The optimal temperature is 95 °C, when sodium percarbonate is decomposed 85%. The result agrees well with the experimental data.

Discussions and conclusion

Our mathematical model is simple for qualitative analysis of the degumming process. A more accurate model is under development using fractal calculus [9-13], and the model equation can be solved by some an analytical method, *e. g.,* the homotopy perturbation method [14, 15], or Taylor series method [16].

Our technology is totally green process with greatly economic feasibility. It can remarkably reduce use of the poisonous chemicals and can avoid completely the use of strong alkali in the degumming process. This environmentally friendly method is a promising technology for mass treatment of ramie fibers in future. At a suitable temperature, the degumming process can remove gum materials from ramie bast with highest output of ramie fibers and zero environmental effect. Our method also results in a good surface treatment of ramie fibers for some special applications.

Acknowledgment

This work was supported by a grant from the Natural Science Foundation of Yancheng Institute of Technology (KJC2014011), Industry-Academia Cooperation Innovation Fund Projects of Yancheng Institute of Technology (2018042705), and Yancheng Institute of Technology Undergraduate Training Programs for Innovation (FZ201814).

References

[1] Liu, Z., *et al.*, Effect of Na_2CO_3 Degumming Concentration on LiBr-Formic Acid-Silk Fibroin Solution Properties, *Thermal Science, 20* (2016), 3, pp. 985-991
[2] Liu, F. J., *et al.,* A Delayed Fractional Model for Cocoon Heat-Proof Property, *Thermal Science, 21* (2017), 4, 1867-1871
[3] Yu, D. N., *et al.*, Snail-Based Nanofibers, *Mater. Lett. 220* (2018), June., pp. 5-7
[4] Zhou, J. J., *et al.*, Property of Ramie Fiber Degummed with Fenton Reagent, *Fibers and Polymers, 18* (2017), 10, pp. 1891-1897
[5] Jiang, W., *et al.*, A Green Degumming Process of Ramie, *Industrial Crops and Products, 120* (2018), Sept., pp. 131-134
[6] Shen, M., *et al.*, Effect of Low-Temperature Oxygen Plasma on the Degumming of Ramie Fabric, *Journal of Cleaner Production, 92* (2015), April., pp. 318-326
[7] Angelini, L. G., *et al.*, Ramie Fibers in a Comparison Between Chemical and Microbiological Retting Proposed for Application in Biocomposites, *Industrial Crops and Products, 75, Part B* (2015), Nov., pp. 178-184
[8] Gao, S., *et al.*, Steam Explosion and Alkali-Oxygen Combined Effect for Degumming of Kenaf Fiber, *BioResources, 10* (2015), 3, pp. 5476-5488
[9] He, J.-H., Fractal Calculus and its Geometrical Explanation, *Results in Physics,10* (2018), Sept., pp. 272-276
[10] Li, X. X., *et al.*, A Fractal Modification of the Surface Coverage Model for an Electrochemical Arsenic Sensor, *Electrochimica Acta, 296* (2019), Feb., pp. 491-493
[11] Wang, Y, An, J. Y., Amplitude-Frequency Relationship to a Fractional Duffing Oscillator Arising in Microphysics and Tsunami Motion, *Journal of Low Frequency Noise, Vibration & Active Control*, on-line first, https://doi.org/10.1177/1461348418795813
[12] Wang, Y., Deng, Q., Fractal Derivative Model for Tsunami Travelling, *Fractals, 27* (2019), ID 1950071
[13] Wang, Q. L., *et al.*, Fractal Calculus and its Application to Explanation of Biomechanism of Polar Bear Hairs, *Fractals, 26* (2018), 6, ID 1850086
[14] Wu, Y., *et al.*, Homotopy Perturbation Method for Nonlinear Oscillators with Coordinate Dependent Mass, *Results in Physics 10* (2018), Sept., pp. 270-271
[15] Yu, D. N., *et al.*, Homotopy Perturbation Method with an Auxiliary Parameter for Nonlinear Oscillators, *Journal of Low Frequency Noise, Vibration & Active Control* (2018), On-line first, https://doi.org/10. 1177/1461348 418811028
[16] He, J.-H., Ji, F.-Y., Taylor Series Solution for Lane-Emden Equation, *Journal of Mathematical Chemistry*, On-line first, https://doi.org/10.1007/s10910-019-01048-7, 2019

Paper submitted: May 18, 2018
Paper revised: November 14, 2018
Paper accepted: November 14, 2018